Material Handling Automation - Trends, Vision, and Future Plans

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Abstract: Key factors driving the proliferation of automated material handling systems (AMHS) in wafer fabs at Intel have been analyzed. The paper looks at major AMHS technologies that have surfaced, what manufacturing problems they are helping solve, its factory acceptance, and the de-facto standards being created. In addition, it will explore specific configurations Intel is considering for future automation requirements, and evaluate the critical infrastructure and supporting elements necessary for making AMHS an enabling asset in the factories of the future.

Introduction

The explosive growth of the semiconductor industry has impacted the role of factory automation (FA) significantly. A key FA component called automated material handling system (AMHS), has been increasingly used in 200 mm fabs at Intel. Functionally, AMHS is divided into interbay and intrabay systems. Interbay is transportation and storage of lots and reticles between processing bays in a fab. Intrabay is material movement within a bay or area, and includes loading and unloading process and metrology equipment.

The primary reasons cited [2] for the acceptance of AMHS applications in wafer fabs are shown below:

- superior lot storage efficiency compared to manual racks
- predictable transportation across very long distances
- people freed from boring and repetitive tasks
- elimination of ergonomic and safety incidences
- improvements in tool output and area throughput times
- cost-effective return on investment
- significant reduction of human-induced variability

Performance data indicate that manufacturing demands on interbay and intrabay systems are very different [2]. Interbay is the baseline (infrastructural) element of the overall system, and must be operational and well understood by the factory for intrabay to be cost-effective. Otherwise, intrabay systems will exist as stand-alone islands of automation and will not reach their real potential. Prior to large-scale intrabay attempts, interbay implementation is a necessity for any semiconductor manufacturer.

Current factory trends driving AMHS requirements:

Intel’s operational and business trends are influencing AMHS. Broadly, these trends can be summarized as:

- Logistics issues arising from large factories
- Innovative (and rapid) factory expansions
- Layout flexibility for process and equipment changes
- Hiring and training a large number of people
- Quick factory ramp expectations
- Increased tool output
- Ergonomics and operational safety

Newer fabs coming on line are large compared to their predecessors, from a standpoint of wafer-starts as well as size of the cleanroom. These factors, coupled with the number of process steps in the manufacturing flow, makes manual transport very difficult. Staggering bay-to-bay throughput volumes ranging between 500-1,000 lots per hour are needed. Interbay systems have been configured to meet these challenges. As a result, Intel’s interbay transport loops are now typically 2,000 to 6,000 feet long and interconnect 40 to 120 clean stockers in a factory.

Fab building structures are now designed for rapid expansion capability. In addition to expanding a cleanroom in the typical north, south, east and west directions, multi-level processing are a distinct possibility. Interbay systems, coupled with inter-floor transport elevators, must provide high-volume lot transport between different manufacturing areas in the building. This approach helps to minimize building footprint and reduces many operational and logistical issues.

To support important factory layout needs such as metrology stations adjacency to major processing areas, and to reduce metrology equipment duplication, today’s fab have become more “metrology-centric”, especially from a manufacturing technician (MT) point of view. This layout approach is considered optimal for both material flow and efficient MT interaction. Stockers placed in the zone between manual metrology and automated bays, physically separates moving robotic equipment from people, and helps to improve operational safety and people communications.

Since a factory is typically subject to frequent process equipment and layout changes, the automation approach has to support this need for flexibility and quick changeout. Intel’s approach is to use a standard solution for intrabay - one type of vehicle-robot configuration that works for many different bay types. This approach simplifies training and maintainability needs and recovering from system problems and anomalies is also easier with such a uniform approach.

New fab startups have created a significant increase in the number of skilled personnel required for manufacturing. In addition to hiring large numbers of people, Intel is faced with a

big increase in other support systems and costs such as training, and relocation. Factory production ramps can be greatly impacted by the lack of availability of trained people. Intrabay applications can be applied to minimize the need for a corresponding increase in direct labor on the fab-floor. In new fabs, people on the factory floor work on difficult manufacturing, equipment, and process problems where humans generally excel, leaving repetitive tasks such as transport, storage, and loading/unloading of tools to the intrabay AMHS. Based on a comprehensive return on investment (ROI) analysis, intrabay systems have been justified in diffusion and lithography areas at Intel. ROI analysis for other key areas continue.

Another trend is to implement intrabay AMHS at factory (output) constraint areas to directly increase factory output. This specifically includes the lithography area. The intrabay robotic vehicles in these bays are programmed to feed the constraint process equipment non-stop, enabling the tool to run constantly without interruption, and completely eliminating any dead-time between successive lot processing. In addition to this mechanical automation, simple scheduling rules can be used to minimize the complexity of lot selection, to synchronize reticle (mask) delivery at each stepper, and to further streamline output of this constraint. The litho MT directs the intrabay automation system from the metrology areas, making this area a de-facto fab command center.

Intrabay has also been effectively used to eliminate ergonomic and safety issues. Prime candidates are diffusion and wet processing, where there is a potential for these problems due to large batch size loads. Lithography and other functional areas are being automated to overcome problems associated with high-frequency cassette loading and unloading at the tools.

Discrete event simulation modeling has been extensively used for the last ten years at Intel for AMHS design verification. It is the only effective analysis tool that can predict and accurately comprehend manufacturing variability for AMHS designs [1]. AMHS must be designed to peak or burst modes of operating conditions (not to average values) to work responsively in high volume. To model these systems accurately, a detailed understanding of hourly processing variability at each work-center in the factory is a pre-requisite for an automation design engineer.

Interbay directions and trends

Interbay system attributes are driven by the need to provide reliable and uninterrupted high throughput material movement across long transportation distances. Overhead monorail transport systems have eclipsed ground based AGV systems for interbay transport because of their superior throughput (1.6X better) capability, smaller footprint, and ability to run multiple loops for highest throughput. Overhead transport systems also eliminate potential safety hazards of people having to co-exist with ground-based AGVS along the main aisles. Two commonly used monorail configurations are shown below:

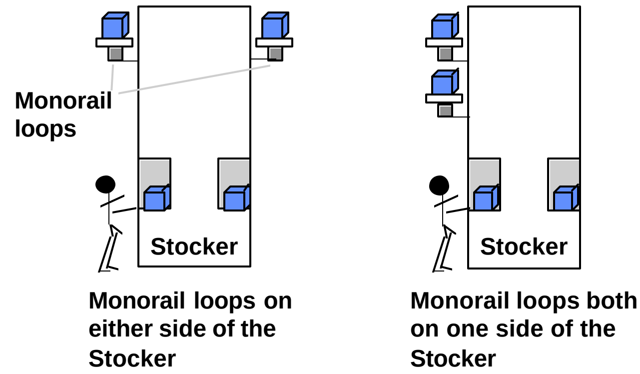

Fig. 1 Two commonly used monorail configurations

Two critical factors have shaped the interbay transport evolution at Intel. One is the ability to transport different load types on the same vehicle. Unlike in the past when dedicated vehicles and monorail loops were used, an interbay vehicle can now carry wafer boxes, open cassettes or reticle box on the same monorail loop. This enabling capability reduces the overall footprint of the AMHS system and increases tool layout flexibility. Dedicated stockers for each of these load types still continue to be used.

The second factor is minimizing lot transportation time (called delivery time at Intel) from stocker to stocker. To meet this objective, the primary goal of the interbay design is to provide maximum throughput bandwidth. Several lessons have been learned. For example, the most optimum stocker location in terms of interbay throughput and process equipment layout versatility is to locate it at one end of the bay and not in the center of the bay. Intel uncovered stocker cycle time to be a key element limiting interbay throughput and has driven a 60% reduction in the last few years. Also, the use of components which merge, diverge or switch track, used to increase track flexibility, tends to compromise interbay throughput. The cycle time for interbay vehicle entry or exit into/from the main monorail loop, as well as the vehicle stopping time at stockers for either unloading or loading, are key candidates for cycle time reduction in the near future to further increase interbay throughput.

Currently, the dominant interbay vehicle drive technology is wheel based designs. For cleanliness reasons, magnetic levitation drive systems were once investigated. However, today there are well engineered solutions such as track fan-filter units or sealed drive-wheel designs. As a result, wheel-based systems now have the capability for supporting interbay cleanliness requirements many years into the future.

Stockers with integrated air-handling systems are another approach to minimizing AMHS dependency on facility systems. With this approach, no air-handling connections are required to the stocker from the facility systems. This makes a stocker a stand-alone unit and increases its placement flexibility. A disadvantage, however, is inability to tightly control clean air temperature and humidity limits within a stocker which may be required in some cases.

Inter-floor material transport elevator systems spanning multiple fab levels are also being investigated. However, relevant U.S. building and safety code restrictions (e.g., H6) have to be comprehended prior to its selection. This feature gives manufacturing engineers more flexibility in process equipment layout options, permits stacking of cleanroom levels one on top of the other, and maintain minimum building footprint. Multiple pairs of elevators (for redundancy and throughput reasons) will be connected at both ends of the interbay loops at each fab level for better load distribution and uniform throughput. These elevators will move lots from the interbay loop(s) on one level to the loop(s) on another fab level. Elevators can also provide many other unique opportunities such as placing the main reticle (large capacity) stocker on the lower level beneath the main lithography area, and allow for reticle delivery right into middle of the litho area for a very efficient operation.

Intrabay trends:

The fab world is still divided between factories using boxes and those using open cassettes. Box supporters claim that use of boxes help to minimize particle deposition on wafers over time, especially during periods of unplanned electrical outages to a facility. Open cassette proponents retort that boxes add particles to the wafer each time it is opened or closed. The debate still continues even to this day.

From an AMHS standpoint, open cassette fabs clearly offer the greatest flexibility to gradually transition to total intrabay automation if so desired. Boxes are a hindrance to intrabay. These facts are based on Intel's intrabay experience in fabs with boxes. There are significant logistical problems to overcome with intrabay box opening/closing, automatic cassette extraction and insertion, and empty-box handling and storage. Additionally, stockers supporting boxed intrabay systems are subject to 50%-70% additional cycles of operation compared to their open cassette counterparts. These factors increase complexity of the software control system and robotic handling equipment, leading to increased cost. However, airborne molecular contamination (AMC) issues in the future may mandate closed carriers for wafers. In such a situation, 200 mm intrabay experience with boxes may be beneficial and strategically worth the effort.

A lack of standardization of 200 mm process equipment load ports has led each equipment maker to adopt a load port configuration that is unique and different. As a result, expensive multi-axis (typically 6-axis) robots are required for intrabay to load this wide range of load port configurations. But there are safety issues to overcome when using open six-axis robots on moving vehicles in the U.S. Attempts of trying to shroud the robot within a safety enclosure has proved to be very costly and this enclosure around the robot also resulted in a major increase in overall vehicle dimensions, making it so inefficient that most companies have abandoned that approach in the U.S. At the same time, sales literature indicate that open robots on AGVS are selling well in Japan and the Far East, perhaps aided by the fact there are no safety restrictions governing their use on vehicles in that part of the world.

200 mm intrabay vehicles are either the rail guided vehicle (RGV) or the free-roving AGVS type. Both are ground based systems. AGVS have lower throughput and also require battery charging stations which take up valuable fab floor space. Three to four AGVS may be needed per bay to meet throughput, where as just two RGVS may be sufficient. But RGVS are considered relatively inflexible from a layout standpoint, and attempting to install a new intrabay rail in the floor during factory ramp may cause manufacturing interruptions if not carefully planned. For this reason the current trend at Intel is to install the rail at fab start-up so as to eliminate any manufacturing impacts during production ramp.

Table 1. Relative comparisons of Intrabay configurations

Vehicle type	Throughput per vehicle	Time to position for load/unload	Routing flexibility
Rail guided vehicle	Very good	Very good	Poor
Tape guided AGVS	Good	Poor	Very good
Free-roving AGVS	Good	Poor	Very good

Carrier handling mechanism	Cycle time to load or unload	Placement versatility
Multi-axis robot	Poor	Very good
Simple 2-axis shuttle	Very good	Very poor

From Table 1, it can be seen that an intrabay technology selection is neither straightforward nor easy. Due to reasons cited above and especially from a safety and throughput standpoint, Intel's intrabay in litho and diffusion is a single rail-guided approach with the robot in a safety enclosure. Rails are installed in the cleanroom floor at factory start-up. Systems are quickly transitioned into production with meticulous pre-planning as the process stabilizes.

The future - 300 mm and Standards

To reduce overall cost of ownership to the factory, Intel is actively engaged in supporting non-proprietary 300 mm SEMI standards activities. For example:

- Wafer carrier standard for 300 mm is one of the most strategically important items. Carrier architectures that will be compatible for several process generations into the future are being evaluated and pursued.
- Process equipment adherence to SEMI E-15 and E-23 load port specifications will be mandatory. This includes capability of overhead carrier delivery and its easement into tool load ports. See Fig. 2 for more details.
- Tools shall be designed to minimize need for maintenance access in the front face of the tool where load ports exist, and where the intrabay vehicle is likely to be operational. In addition, tools shall be designed for installation along a straight line, which guarantees alignment of the tool load ports across all equipment in that bay.

- Standard <u>uni-cassette capability</u> (wafers return to same carrier and same slot) is required for all tools. This feature greatly reduces operational complexity and also eliminates need for frequent wafer ID verification. Uni-cassette has the potential to also provide yield diagnostic information as it can now discern wafer position trends.
- <u>Use of lot-buffering at tool ports</u> increases process tool output (through lot-cascading) and provides the ability to keep the process tool running non-stop. Intrabay vehicles are configured to feed the tool buffer non-stop, thereby preventing the constraint tool from ever running out of material to process. SEMI standards are being initiated.
- Standards in software interfaces (tool to station controller and tool to intrabay system) also are being pursued. These include standard SECS/GEM message sets coupled with simpler anomaly handling capability.
- Standards covering interfaces between automation, process equipment and facilities are also being supported.

Future 300 mm AMHS systems

Selection of 300 mm AMHS equipment will be based on the supplier's ability to demonstrate integrated systems that meet or exceed safety requirements, reduced cost of ownership, smallest footprint, high throughput, ease of use, layout and installation flexibility, higher reliability and increased maintainability.

The overhead transport monorail will likely remain the choice for interbay. There are several emerging variations of this technology, in particular, vehicles with hoists now appear to be viable, since they can deliver material to stockers or directly to process equipment load ports, as shown in Fig. 2. This configuration will cause some blurring in the current definitions of interbay and intrabay.

Stockers are in for some big changes because 300 mm 25 wafer lots will require about a 2X increase in stocker footprint if a 200 mm stocker is just scaled-up. New ideas are being explored such as the zero footprint storage (ZFS), with the goal of not increasing stocker footprint to cleanroom area ratio for 300 mm. However, there are many challenges ahead, such as process tool height variations, utility system interference, laminar air flow obstruction potential, process tool move-in paths, and overall maintainability and complexity roadblocks.

Emerging 300 mm SEMI standards for tool ports and carriers will greatly simplify intrabay complexity compared to what exists for 200 mm. The need for sophisticated multiple-axis robots for carrier load/unload will become less of a necessity in the future as uniform load-port configurations emerge across all tool types. It is predicted that a simple 2-axis shuttle mechanism fixed on floor-running vehicles will replace the 6-axis intrabay robot. Vehicles will be either free roving AGVS or rail-based designs based on user's preference. Rail based systems with hoists suspended from the ceiling are another option that users may consider, since they have a potential of reducing bay widths, as shown in Fig. 2. Hoist cleanliness requires improvement to meet next-generation cleanliness goals.

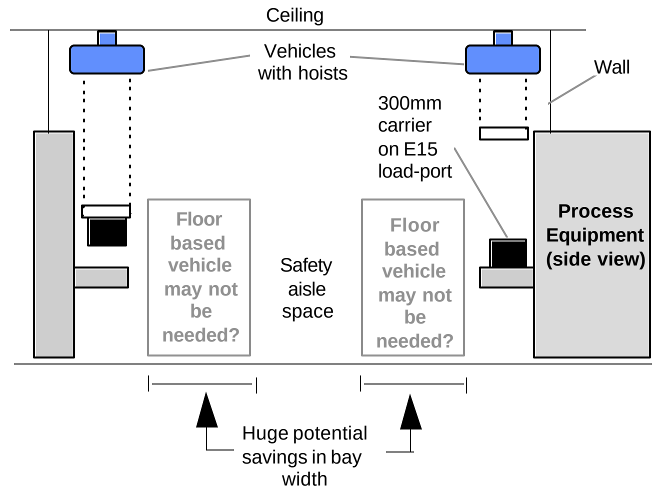

Fig. 2 Bay width savings with hoist based Intrabay systems

Despite these new ideas, the time proven manual cart will continue to be used for lot transportation in the cleanroom. Simple (clean) sliding mechanism are likely to be used on carts to eliminate the need for manual lifting and set-down of the carriers by people.

Metrology tools will also see more automated load/unload functionality. The interaction between intrabay, manual metrology operation, and layout implications must be understood prior to any major FA undertaking in this area.

Future role of AMHS in factory integration

As intrabay becomes pervasive, operational command centers will emerge and must be integrated into the layout. Using simplified (automated) scheduling rules, shop-floor personnel of the future will remotely run the factory floor from these locations. This will be a new paradigm for semiconductor manufacturing.

Compared to their 200 mm counterparts, 300 mm AMHS will be designed to better integrate into the factory, process, operations, and layout. The key challenge will be maintaining utmost flexibility for process equipment layouts, operation, and maintenance. Better ways of utilizing factory height, reducing laminar air-flow obstruction in the cleanroom, and minimizing interference to ceiling systems, floor utility piping, and laterals are improvement targets.

References:

[1] D. Pillai, "*Designing Material Handling Systems for Large Scale Wafer Fabrication Automation*", Proceedings, SME Conference on Semiconductor Mfg., Nov. 1989.

[2] D. Pillai, "*AMHS Design and Success Criteria - How they are derived*", Intel internal document, Nov. 1993.